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SUMMARY REPORT ON EVENTS RELATED TO LOSS OF OFFSITE POWER AND STATION BLACKOUT AT NPPs

*European Clearinghouse
on Operating Experience Feedback
for Nuclear Power Plants*

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Summary Report of the Topical Study on Events Related to Loss of Offsite Power and Station Blackout at NPPs

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Acknowledgements

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Abstract

This Summary Report presents the results of a comprehensive study (Volkanovski et al., 2015) on Loss of Offsite Power (LOOP) and Station Blackout (SBO) events registered in IRSN (Institut de Radioprotection et de Sûreté Nucléaire), GRS (Gesellschaft für Anlagen- und Reaktorsicherheit mbH) in time period 1992 to 2011 and the Nuclear Regulatory Commission (NRC) Licensee Event Reports (LERs) database and the IAEA International Reporting System (IRS) in the time period 1990 to 2013.

The events were classified considering predefined categories. An analysis of the distribution of the identified events within the categories and type of plant operational modes was performed.

The LOOP frequency was determined for each database and four LOOP event categories: plant centered, switchyard centered, grid related and weather related. The obtained frequencies obtained for critical and shutdown operations are presented.

Based on the observations of the identified LOOP events, the activities that may result in reduction of the number of LOOP events and minimize consequences on plant safety are enlisted.

1 Introduction

The fundamental safety objective, as defined by the International Atomic Energy Agency (IAEA, 2006) is to protect people and the environment from the harmful effects of the ionizing radiation. The prime purpose of the nuclear safety is prevention of the release of radioactive materials formed in the nuclear fuel, ensuring that the operation of nuclear power plants does not contribute significantly to the individual and societal risk.

The nuclear safety is fulfilled in the nuclear power plants with provision, in all situations, of the basic safety functions (IAEA, 2012):

- Control of reactivity
- Removal of decay heat to the ultimate heat sink
- Containment of radioactive materials

The basic safety functions shall be assured either by inherent safety features relying on the laws of nature (IAEA, 2009) or reliable active safety systems designated for realization of these functions. The operating nuclear power plants have safety systems that are in general active requiring electrical energy for their activation and operation.

The loss of offsite power (LOOP) initiating event occurs when all electrical power to the plant from offsite power system is lost.

The electrical power after the LOOP is expected to be provided either by the plant generator or, in case of unsuccessful decrease of output power to house load, by the emergency diesel generators (EDG).

Loss of alternating current (AC) to the essential and nonessential switchgear buses in a NPP (i.e., loss of off-site electric power system concurrent with turbine trip and unavailability of the on-site emergency AC power system) is referred to as station blackout (SBO).

This Summary Report presents the main results of the analysis of LOOP events identified in four databases elaborated extensively in the Topical Study (Volkanovski et al., 2015). The description of the database screening methodology and events classification is given in Section 2. The results of the analysis of identified events are given in Section 3. Main observations based on the identified events are listed in Section 4. The conclusions are given in Section 5.

2 Events identification and classification methodology

Identification of the relevant LOOP events in the analysed databases was done in two steps:

- First the databases were searched to identify potential events for consideration.
- Search results were reviewed with selection and classification of the relevant events.

Database searching was done with relevant "guidewords" and "keywords" identified in relation with the "LOOP and SBO" topic. All identified events in the search of the databases were carefully analysed. The relevant events were selected and classified based on predefined criteria. The methodology for events screening and selection was also applied to the analysis of the EDG failures (Kančev et al., 2014).

The database SAPIDE, owned and managed by IRSN, and the database VERA, owned and managed by GRS, were screened for relevant events reported for the period from 01/01/1992 to 31/12/2011.

The US NRC LERs database and IAEA Incident Reporting System (IRS) (IAEA, 2010) database were searched to identify representative LOOP related events for the period 1990-2013 with utilization of the available databases search tools and relevant

keywords. The widespread grid disturbance which happened on August 14, 2003, affected nine NPPs sites with eleven reactors, was taken into account. Five of those events were selected and considered further in the analysis.

The selected LOOP events were classified into categories considering the following factors: plant status, circumstances, type of event, type of equipment failed, direct and root cause, consequences of the event and event duration. Each event was classified into single best matching category with the exception for the characteristic related to the type of equipment failed and the consequences, which can be multiple.

3 Analysis of identified events

Table 1 shows the number of events identified in the analysed databases for different plant status.

Table 1: Number of selected events for different plant status and database

Database source	Number of events			
	FRANCE	GERMANY	USNRC	IAEA IRS
PLANT STATUS				
On power	145	102	76	47
Hot Shutdown	25	12	7	0
Cold Shutdown	58	76	37	5

Table 1 shows that largest number of LOOP events are registered during power operation followed by cold shutdown.

The LOOP events are subdivided into four types by cause or location: plant centered, switchyard centered, grid related, and weather related. These four LOOP categories are assessed for two modes of operation (critical and shutdown operation). The categorization of the LOOP events is based on the categorization and description of the LOOP categories given in the document NUREG/CR 6890 (NRC, 2005).

The assessment of the LOOP frequency requires as input the total reactor critical or shutdown years for the analyzed data period. The total reactor critical and shutdown years for the analyzed countries and databases are assessed from the number of the operating NPPs and their operating factor (OF) representing the ratio of on-line hours to total hours. The number of the operating reactors is assessed from (IAEA, 2015a). The average operating factor of the reactors in each year is determined from the Country Nuclear Power Profiles given in IAEA Power Reactor Information System (IAEA, 2015b).

3.1 Obtained LOOP frequencies

Obtained LOOP frequencies for the analysed databases are given in Table 2 to Table 4. The first column of the tables defines the plant operational mode (critical/shutdown) with LOOP categories given in the second column. The number of identified events for each category and mode is given in third column. The mean frequency of the LOOP events per reactor critical (rcry) or shutdown year (rsy) is given in the fourth column. The LOOP frequency is obtained by dividing the number of the identified events by the reactor critical and shutdown years.

The LOOP frequencies obtained for the French and German NPPs during critical operation, as shown in Table 2 and Table 3, are of same order of magnitude. The frequency of the LOOP events is twice larger for German plants compared to the French NPPs. Table 2 and Table 3 show that plant related events are the dominant contributors to the events in the IRSN and GRS databases.

Table 2: Plant-level LOOP frequencies assessed from IRSN database

Mode	LOOP category	No. of Events	Mean frequency	Frequency Units
Critical operation	plant	110	1.23E-1	/rcry
	switchyard	26	2.90E-2	/rcry
	grid	3	3.35E-3	/rcry
	weather	6	6.70E-3	/rcry
	All	145	1.62E-1	/rcry
Shutdown operation	plant	71	3.00E-1	/rsy
	switchyard	11	4.65E-2	/rsy
	grid	1	4.23E-3	/rsy
	weather	0	0	/rsy
	All	83	3.51E-1	/rsy

Table 3: Plant-level LOOP frequencies assessed from GRS database

Mode	LOOP category	No. of Events	Mean frequency	Frequency Units
Critical operation	plant	81	2.93E-1	/rcry
	switchyard	2	7.23E-3	/rcry
	grid	16	5.78E-2	/rcry
	weather	3	1.08E-2	/rcry
	All	102	3.69E-1	/rcry
Shutdown operation	plant	75	9.22E-1	/rsy
	switchyard	1	1.23E-2	/rsy
	grid	9	1.11E-1	/rsy
	weather	3	3.69E-2	/rsy
	All	88	1.08	/rsy

Table 4: Plant-level LOOP frequencies assessed from US NRC database

Mode	LOOP category	No. of Events	Mean frequency	Frequency Units
Critical operation	plant	14	6.73E-3	/rcry
	switchyard	42	2.02E-2	/rcry
	grid	7	3.37E-3	/rcry
	weather	12	5.77E-3	/rcry
	All	75	3.61E-2	/rcry
Shutdown operation	plant	13	2.61E-2	/rsy
	switchyard	23	4.62E-2	/rsy
	grid	4	8.03E-3	/rsy
	weather	5	1.00E-2	/rsy
	All	45	9.03E-2	/rsy

The difference of the assessed LOOP frequencies between the French and German NPP's is even larger for shutdown operations. A frequency of at least one LOOP per shutdown year is obtained for German nuclear power plants.

A value of $3.61\text{E-}2$ /rcry is calculated for LOOP frequency during critical operation for the US NPPs, as indicated in Table 4, which is comparable to the $3.59\text{E-}2$ /rcry assessed in NUREG/CR-6890 (NRC, 2005). The LOOP frequencies for shutdown operations listed in Table 4 are smaller than the frequencies assessed in (NRC, 2005).

Table 1 shows that very few LOOP events are reported in IAEA IRS and therefore not considered as representative for LOOP frequency assessment.

3.2 Plant status

The largest number of LOOP events in IRSN SAPIDE is registered for the plant centered events, followed by the switchyard centered events. The 64 % of the events are registered during the critical operation mode followed by cold and hot shutdown events.

The plant centered events are identified with the largest number in the GRS VERA database. The distribution of the events considering plant status shows that 40 % of all events in the GRS VERA database are registered during cold shutdown. This is an expected result considering the extensive time of the German NPPs in cold shutdown in the analysed period.

Figure 1 shows that the largest number of events in U.S. NRC LERs database is registered for the switchyard related events contributing to 54 % of all registered events. Plant-centered LOOPS is the second largest group with 23% followed with weather related events with 14% and grid related events with 9% of all registered events. The identified share of plant and weather related events is identical to the shares identified in the report (NRC, 2005), with comparable shares for grid and weather events.

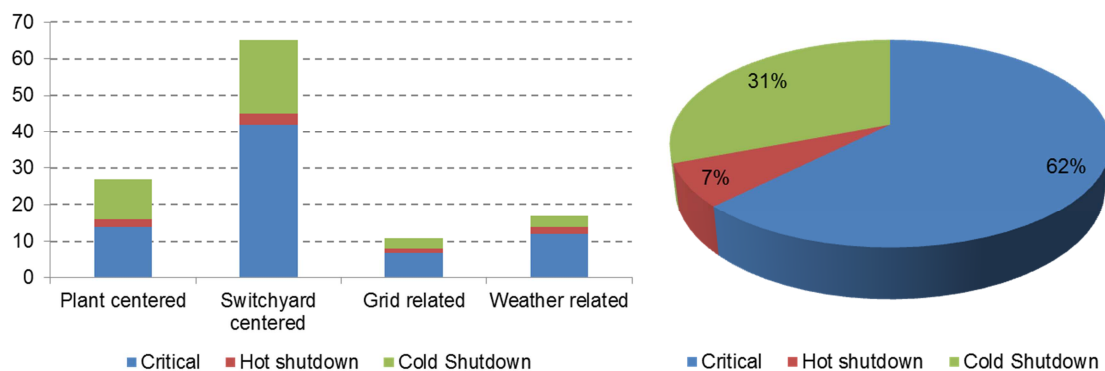


Figure 1: LOOP events distribution by category "Plant status" (U.S. NRC LERs)

Figure 1 show that largest percentage of the events with 62% is registered during the critical operation followed by 31% during cold shutdown and 7% during hot shutdown operation.

The 90% of the events in the IAEA IRS database are registered during critical operation with 10% during cold shutdown.

The results obtained show that the largest numbers of events are reported for plant centered category in the three databases (SAPIDE, VERA, IAEA-IRS). The largest number of the events in the NRC-LER database is identified for switchyard centered events. The largest percentage of the events, considering the mode of operation, is registered during critical operation in all the four databases.

3.3 Circumstances

Figure 2 shows that the largest number of events in IRSN SAPIDE is registered during normal operation contributing to 36 % of all events. Inspection is second largest with 24%, while functional tests and maintenance are contributing 16% of all events. The contribution of the remaining circumstances, as shown on Figure 2, is small.

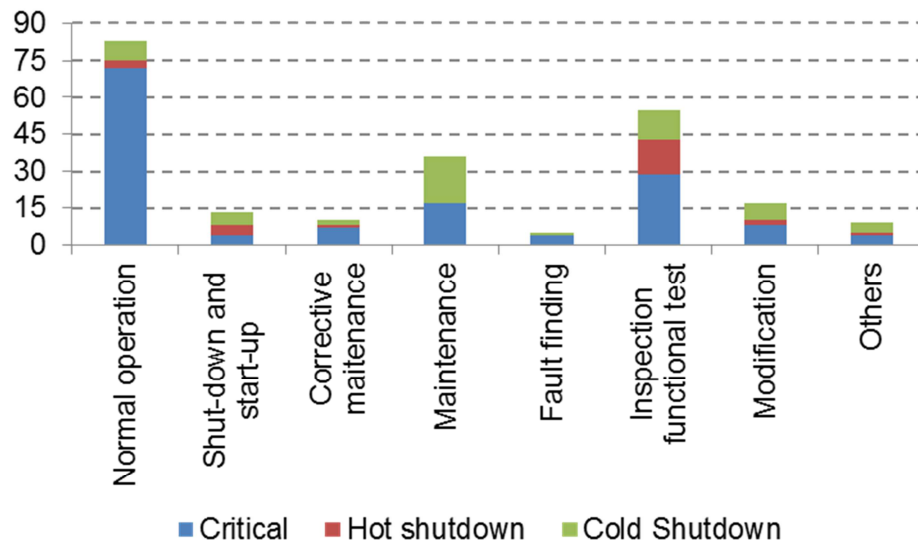


Figure 2: LOOP events counts by "Circumstances" (IRSN SAPIDE)

The largest number of LOOP events in GRS VERA is registered during inspection and functional tests, followed by normal operation and maintenance activities. The obtained result was expected considering the shutdown operation mode of the German NPPs in the analysed period.

In U.S. NRC LERs the largest number of events is registered during normal critical operation, followed by maintenance activities and inspection functional test.

The largest number of events registered in the IAEA IRS database is registered during normal operation with small contribution of other circumstances. The final conclusion from the analysis of all four databases is that the major part of the LOOP events is registered during normal operation of the plant.

3.4 Type of event

The largest number (114 in total) of LOOP events in IRSN SAPIDE is registered for the type "Partial loss of external power" during critical operation. Physical damage of buses, are more severe for nuclear safety. Four events of physical damage of buses are registered in the French database and three of them during cold shutdown operation.

In the GRS VERA database the largest number (53 in total) of events are observed for the type "Physical loss of electrical busbars. All events "Loss of power supply" in GRS VERA are registered during cold shutdown mode.

The largest number (29) of events in U.S. NRC LERs is registered for "Partial loss of external power" events. Smaller but comparable number (26) of events is registered for the "Total loss of external power" events. The largest number of those events in U.S. NRC LERs is registered during critical mode of operation.

The "Loss of power to busbars" events have largest number (19) followed by total (17) and partial loss (10) of external power in IAEA IRS. The major number of events is identified during the critical operation mode.

From the analysis in this section it can be concluded that the largest number of "Partial loss of external power" events is registered in the IRSN and NRC databases. In the GRS and IAEA databases the main type is "Physical loss of electrical busbars". The events in these groups are registered mainly during the critical mode of operation.

3.5 Type of equipment failed or concerned

In this section the events in the analysed databases are sorted by the type of the failed equipment and mode of operation.

The largest number of events in IRSN SAPIDE is registered for Switchyard/Breaker failures followed by the interconnections (lines and transformer) failures.

The largest number of events in the GRS database, as shown on Figure 3, is observed for the busbar failures followed by the transformer failures. About half of the busbar failures and more than half of the transformer failures, as shown on Figure 3, are registered during cold shutdown. A large number of inverter failures is also identified in the GRS VERA database.

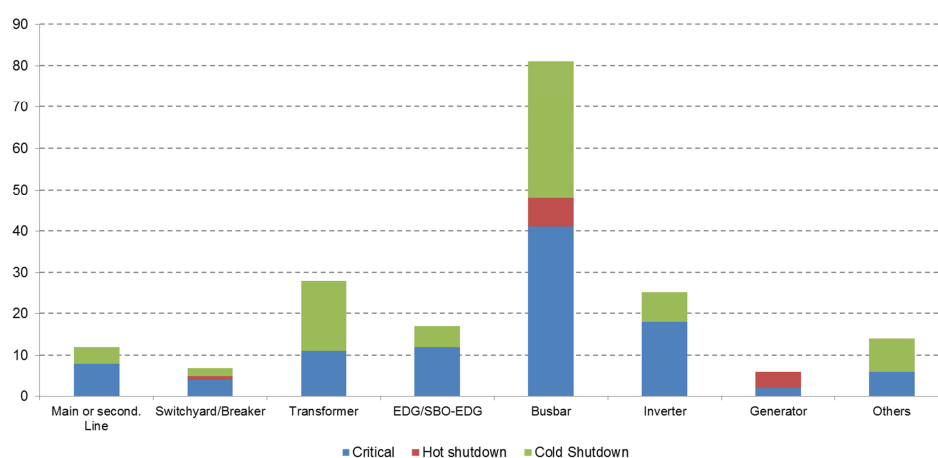


Figure 3: LOOP events counts by "Type of equipment failed" (GRS VERA)

The largest number of events in U.S. NRC LERs is registered for the primary or secondary power line followed by the failures in switchyard and transformers. The largest number of events IAEA IRS are registered for the switchyard/breaker failures followed by the transmission lines failures.

The largest number of events, obtained from the analysis of all four databases, is registered for the switchyard failures followed by the interconnections failures (both lines and transformers).

3.6 Direct cause

The largest number of events in IRSN SAPIDE is plant related, registered during critical operation. The main direct cause for those plant related events is human failure (HF), with electrical, instrumentation and control (I&C) failures as second and third largest contributor.

The largest number of events in the GRS VERA is observed for plant related LOOP events during critical operation. Comparable number of events is registered for cold shutdown operation. The dominant contributors in the plant related events are I&C failures.

Figure 4 shows that the largest number of events in U.S. NRC LERs is identified for switchyard failures during critical operation. Figure 4 shows also that electrical failures are dominant contributor to the switchyard deficiency followed by the mechanical and I&C failures. The dominant contributor to the electric grid deficiency is environmental causes outside of the plant.

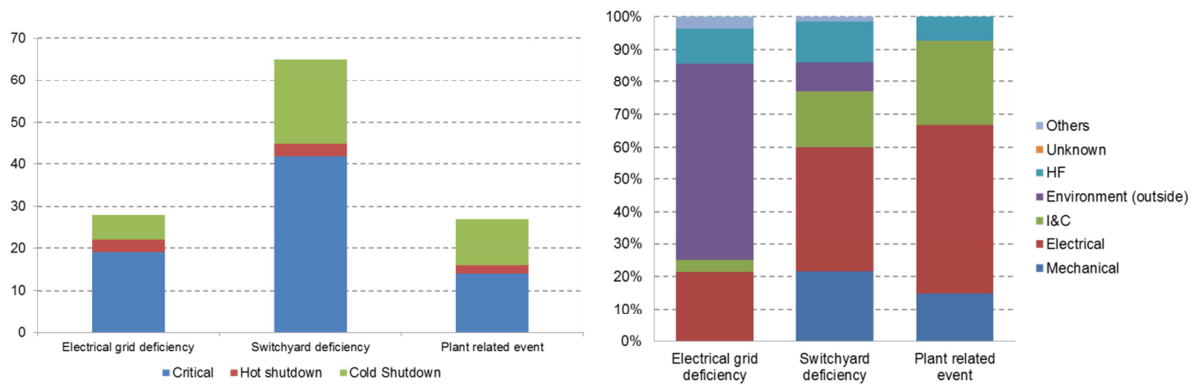


Figure 4: LOOP events counts and share of the specific direct causes in the sub-categories of the "Direct causes" (U.S. NRC LERs)

The largest number of events in IAEA IRS is registered for plant related events, with electrical failures as main cause.

The classification by the "Direct causes" in this section shows that largest number of events is registered for the plant related events in the IRSN, GRS and IAEA databases and switchyard related events in the NRC database. The main cause of the events is electrical deficiency. Environment is registered as main contributor for the electrical grid deficiency in the IRSN and NRC databases. The electrical failures are dominant contributor to the electrical grid deficiency in the GRS and IAEA databases.

3.7 Root cause

The distribution of the sub-categories within the three main categories of the root causes, human performance – HF, equipment related – E and others, for events registered in the IRSN SAPIDE database is given in the Figure 5.

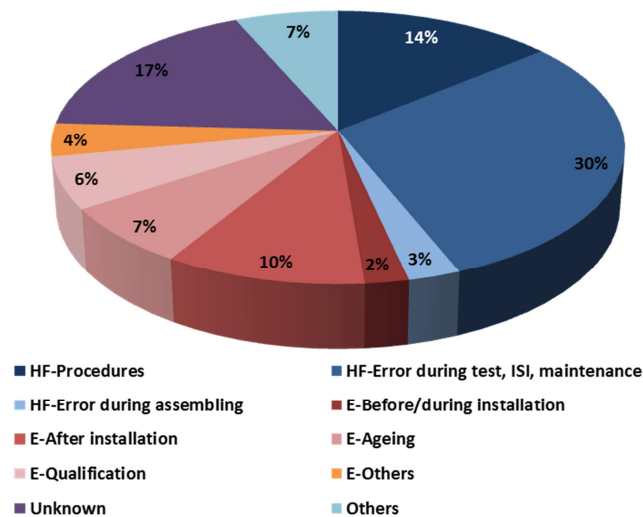


Figure 5: Distribution of the "Root cause" sub-categories (IRSN SAPIDE)

Figure 5 shows that the root cause of more than half of the events is related to the human performance, followed by equipment related events and other failures.

Figure 5 shows also that the largest share of all registered LOOP events has root cause of human failure during tests, service and maintenance, followed by the human failures due to wrong procedures. The third largest share, not considering the unknown causes, is from equipment failures identified after the installation.

The largest number of events in GRS VERA is due to human performance with comparable number of events for equipment related events. The largest known cause is human failure during tests, service and maintenance followed by the human failure due to procedures and non-classified equipment failures.

The largest number of events in the NRC LER is registered for human performance root cause followed by other causes and equipment related causes. The human performance events are registered both for critical and cold shutdown operation.

The largest share in IAEA IRS LOOP events is from equipment failures after the installation followed by the human failures due to the procedures and human errors during test and maintenance.

The dominant root cause for the LOOP events, based on the data presented in this section are human failures. The largest number of those failures is registered during critical operation. Within the human failures the largest sub-group are human errors during test, inspection and maintenance followed by the human failures due to the insufficient or wrong procedures.

3.8 Consequences

The largest number of LOOP events registered in IRSN SAPIDE resulted in reactor trip followed by the offsite line/external system connection switching.

Figure 6 shows that the largest number of LOOP events in GRS VERA resulted in start of SBO EDG followed by internal line switching. Smaller number of reactor trips was expected considering the number of plants in shutdown mode in Germany in the analyzed period.

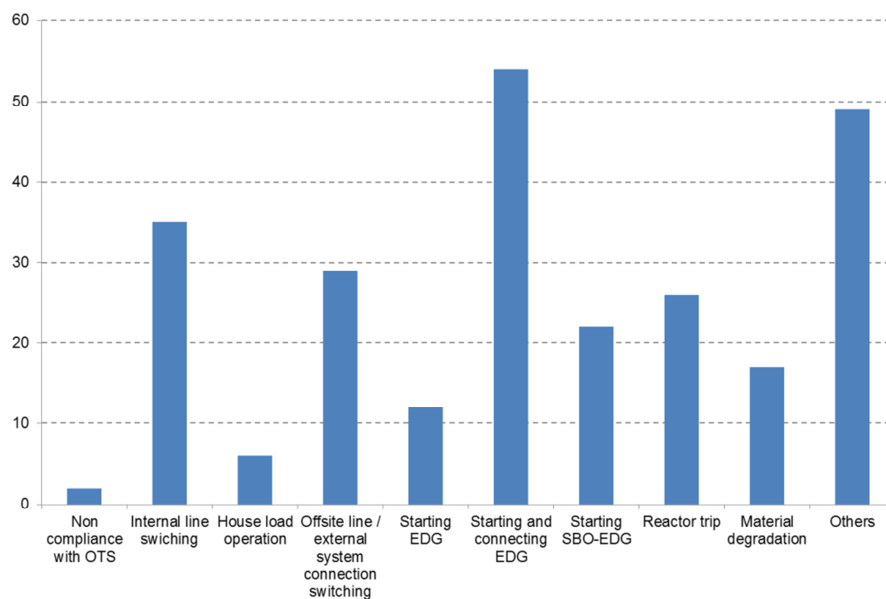


Figure 6: Distribution of "Consequences" (GRS VERA)

The largest number of events in NRC LERs database resulted in start of the EDG followed by reactor trip. This can be attributed to the successful reduction of turbine-generator output from full to house load power output resulting in non-trip LOOP.

The largest number of events in IAEA IRS database resulted in reactor trips followed by starting and connection of the EDG.

From the results presented in this section it can be concluded that the largest number of LOOP events resulted in reactor trip followed by the EDG start.

3.9 Event duration

The largest number of events has duration of 2 minutes or more and the events are registered during critical operation. The major part of the events registered in GRS VERA has an undefined length but, considering their description, it can be assessed that they have duration longer than 2 minutes.

4 Observations on the identified events

Based on the review and analysis of the identified LOOP events the following actions may result in reduction of the number of LOOP events and minimize consequences on plant safety.

- Maintenance activities on offsite power system should be coordinated with maintenance work on on-site power system, especially in conjunction with unavailability of the essential power system trains. External personnel conducting various works on-site should be adequately trained and informed considering accident prevention rules. Verified and clear procedures should be developed and implemented in the plant in order to avoid human failures resulting in LOOP and consequential SBO for the operation, maintenance and testing of electrical systems. Appropriate testing tools and methods should be implemented in order to avoid erroneous actuations of systems and consequential LOOP.
- Adequate rate of the preventive maintenance is necessary to verify the availability and functionality of electrical equipment, especially older equipment with mechanical parts in order to avoid common-mode failures. The regular inspection of the power transformers phases surge arrestors and the ductwork joint seals is recommended in order to decrease the LOOP frequency.
- Improved ageing-assessment program should be implemented for the electrical equipment in the nuclear power plant especially equipment that has transformer oil as isolation including for current and voltage transformers. The ageing assessment should consider load profile of the equipment and environmental conditions. Improved separation of non-safety electrical equipment can limit the damage of the fire in the switchyard.
- The potential for common cause failures triggered by electronic components failures should be minimized with improved selection of installed parts, receiving feedback from the licensees about noticed anomalies, preparation and dispatching of adequate manuals and safe transport of the equipment.
- Application of the adequate methods and tools for assessment of the cable conditions is recommended. The analysis should consider actual environmental conditions on whole route of the cables as well design and actual electrical loads that are powered by that cable. The voltage drop over the cable should be also considered in the analysis.
- Maintenance work on electrical equipment should be minimized during the critical operation mode. Risk analysis of maintenance operations before their realization is recommended for important electrical equipment.
- Adequate consideration of local weather and related consequential phenomena should be done at the design selection of the insulators.
- A well-defined procedure to operate the unit during a fire incident must be established, as the electrical deficiency on power equipment can quickly result in a fire.
- Appropriate separation and isolation should be implemented in the power system design especially when safety related system is powering non-safety related equipment. Modifications of the plant power system with connection of new equipment to the non-safety power system of the plant, increasing independence and decreasing loads on

safety buses can improve power system availability. Potential for fire and explosions should be considered and minimized in the distribution system changes.

- Clearly defined and programmatic (organizational and management) root cause analyses are essential for establishing fully effective corrective actions in order to eliminate scenarios of ineffective resolution of known technical problems.

5 Conclusions

The results of statistical and engineering analysis of the loss of offsite power and station blackout events in four reviewed databases are presented. The identified relevant events were classified into predefined categories considering: plant status, circumstances, type of event, type of equipment failed, direct and root cause, consequences of the event and event duration.

An analysis of the identified events was performed and the LOOP frequency determined for four LOOP event categories: plant centered, switchyard centered, grid related and weather related during both critical and shutdown operation.

For the IRSN database the mean frequency of $1.62\text{E-}1$ events/ per reactor critical year (rcry) and $3.51\text{E-}1$ events/ per reactor shutdown year (rsy) is assessed. For the GRS database a frequency of $3.69\text{E-}1$ events/rcry and $1.08\text{E+}00$ events/rsy are calculated. For both databases the dominant contributors are plant related events. The large frequency of LOOP events registered in the GRS database during shutdown can be attributed to the large number of NPPs in shutdown mode during the analysed period. For the NRC LER database the LOOP frequency of $3.61\text{E-}2$ events/rcry and $9.03\text{E-}2$ events/rsy is determined and is comparable to the frequencies assessed in previous studies. The small frequencies of LOOP events identified in IAEA IRS can be attributed to the small number of events reported in this database limiting their relevance.

In three databases (SAPIDE, VERA, IAEA-IRS) the largest numbers of events are registered for plant centered category, while switchyard centered events have the largest number in the NRC-LER database. The largest percentage of the events is registered during critical operation in all four databases.

The "Partial loss of external power" type events are registered in the IRSN and NRC databases while the "Physical loss of electrical busbars" is the main type in the GRS and IAEA databases.

The largest number of events is recorded for the switchyard failures followed by the interconnections failures (both lines and transformers).

The electrical deficiency is found to be the main direct cause of the events with environment as main contributor for the electrical grid deficiency in the French and NRC databases. The electrical failures are dominant contributors to the electrical grid deficiency in the German and IAEA databases.

The dominant root cause for the LOOP events is human failures with the human errors during test, inspection and maintenance as the largest contributing sub-group.

The largest number of the LOOP events resulted in reactor trip followed by the start of the emergency diesel generators. Most of the identified LOOP events lasted for more than 2 minutes.

Observations based on the analysis of the inedited events in order to decrease the frequency and consequences of LOOP events are enlisted.

References

IAEA, 2006. Fundamental Safety Principles, Safety Standards Series

IAEA, 2009. Passive Safety Systems and Natural Circulation in Water Cooled Nuclear Power Plants, IAEA-TECDOC-1624. IAEA, Vienna.

IAEA, 2010. IRS Guidelines – Joint IAEA/NEA International Reporting System for Operating Experience, Service Series 19. IAEA: Vienna, March 2010, Vienna.

IAEA, 2012. Safety of Nuclear Power Plants: Design, Specific Safety Requirements No. SSR-2/1. International Atomic Energy Agency, Vienna.

IAEA, 2015a. Nuclear Power Reactors in the World, p. 79.

IAEA, 2015b. Power Reactor Information System

Kančev, D., Duchac, A., Zerger, B., Maqua, M., Wattrelos, D., 2014. Statistical analysis of events related to emergency diesel generators failures in the nuclear industry. Nuclear Engineering and Design 273, 321-331.

NRC, U.S., 2005. Reevaluation of Station Blackout Risk at Nuclear Power Plants, NUREG/CR 6890, Washington.

Volkanovski, A., Ballesteros, A., Kančev, D., 2015. Topical Study on Events Related to Loss of Offsite Power and Station Blackout at NPPs. EC JRC/IET, Petten, Netherlands.

List of abbreviations and definitions

AC: Alternating Current

EDG: Emergency Diesel Generator

I&C: Instrumentation and Control

IRS: Incident Reporting System

JRC: Joint Research Centre

LOOP: Loss of Offsite Power

NPP: Nuclear Power Plant

NRC: Nuclear Regulatory Commission

PWR: Pressurized Water Reactor

SBO: Station Black Out

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